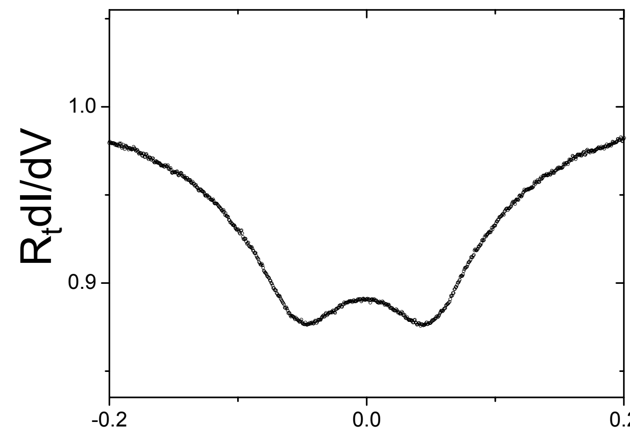
Electron-electron interactions enhanced by dilute magnetic impurities - I

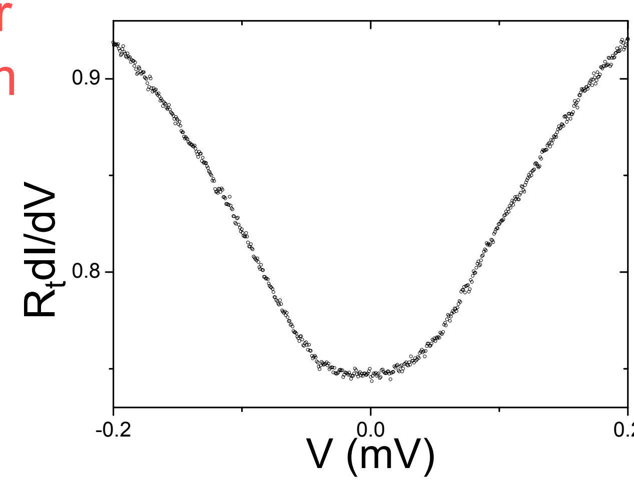
Norman Birge, Michigan State University, DMR-0405238

It is hard to believe that electrical properties of a metal could be dominated by defects that are present at a concentration of only one part per million (1 ppm). But that is indeed the case when the impurity is magnetic, and when one measures either the quantum phase coherence of electrons or the rate at which electrons exchange energy with each other at very low temperature. In this experiment, we measured electron energy exchange in two samples: one made of extremely pure silver, and the other one the same silver but with 1 ppm of manganese impurities added. The different shapes of the two experimental curves demonstrate the strong influence of the magnetic impurities. These data confirm the theoretical predictions of A. Kaminski, L.I. Glazman and others.

99.9999% pure silver



Pure silver with 1 ppm Mn added



Throughout the history of solid-state physics, understanding the role of defects in metals and semiconductors has been crucial both to gain a fundamental understanding and to make technological developments. In the 1950's, different laboratories measuring the electrical properties of semiconductors found different results. Eventually, scientists realized that the behavior they measured depended on the presence of specific types of impurities in the samples. Consistent results were achieved only after scientists learned how to grow extremely pure single crystals of silicon and germanium. After that followed the invention of the transistor, and then the amazing computer revolution that has transformed our lives. In some metals at low temperature, physicists discovered in the 1960's a strange upturn in the electrical resistance of some metals at low temperature. Jun Kondo showed that the upturn was due to a few percent of magnetic impurities, and the "Kondo effect" named after him has since become a powerful paradigm in theoretical physics for understanding a wide variety of experiments in metals and semiconductors. In the past few years, we and others discovered that extremely dilute magnetic – at concentrations of only one part per million – could dominate many low-temperature electrical properties of metals. That discovery may be important for future developments in quantum computation, and also has practical implications for the design of a new kind of far-infrared detector used in astrophysics.

Electron-electron interactions enhanced by dilute magnetic impurities - II

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International Collaboration: This work was carried out in collaboration with H. Pothier, B. Huard and D. Esteve at the CEA Saclay in France.

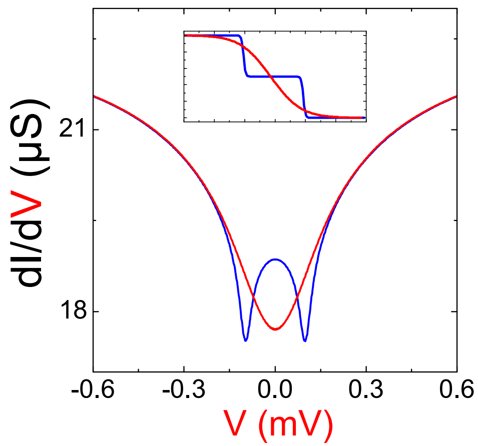
Education: The physical principles and experimental techniques developed in this work are crucial to the future development and applications of nanosciences.

Current graduate students at MSU: Michael Crosser, Ion Moraru, Gassem Al-Zoubi

Recent undergrads: Kevin Dolan, Charles Wallace, John Lighthall

Outreach: The PI co-taught a set of 6 Saturday physics workshops for 3rd-5th graders in France last year, and is looking forward to applying what he learned there to the schools in East Lansing, Michigan.

Broad scientific impact: Understanding the role of magnetic impurities in metals may be important for quantum computing, and has applications in far-infrared detectors used in astrophysics.



Schematic diagram showing the relationship between the electron energy distribution function (inset) and the dI/dV data measured in the experiment shown on the previous page.